



Modeling contamination migration on the Chandra X-ray Observatory — IV

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Outline



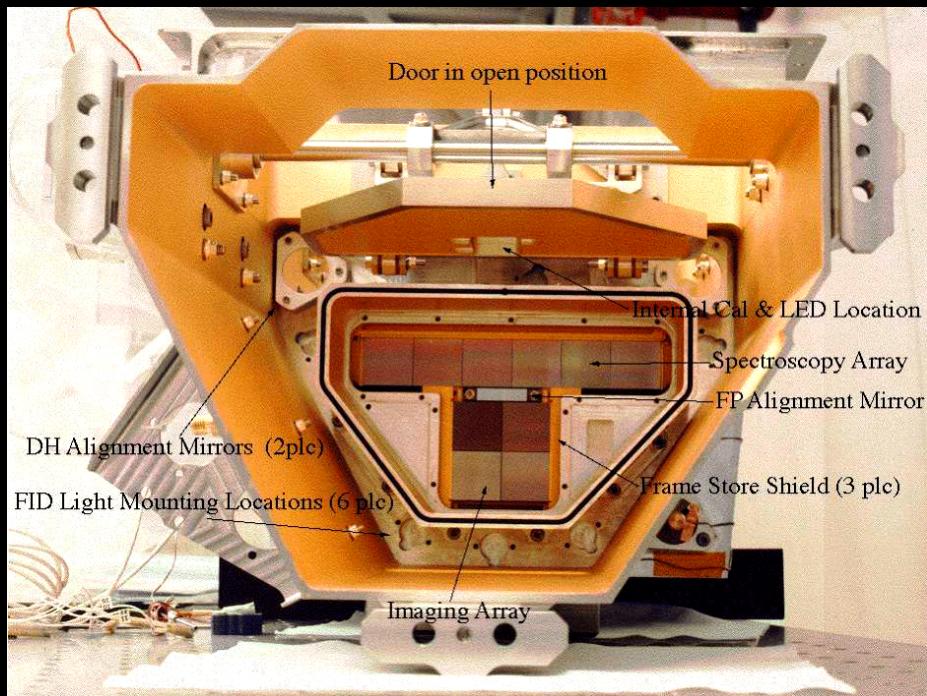
- Introduction
- Molecular contamination on ACIS filters
- Thermal model for ACIS cavity
- Molecular transport simulations
- Summary



Chandra's Advanced CCD Imaging Spectrometer (ACIS)



- ACIS cavity
 - Collimator
 - Snoot & door
 - Camera top & filters (OBF)



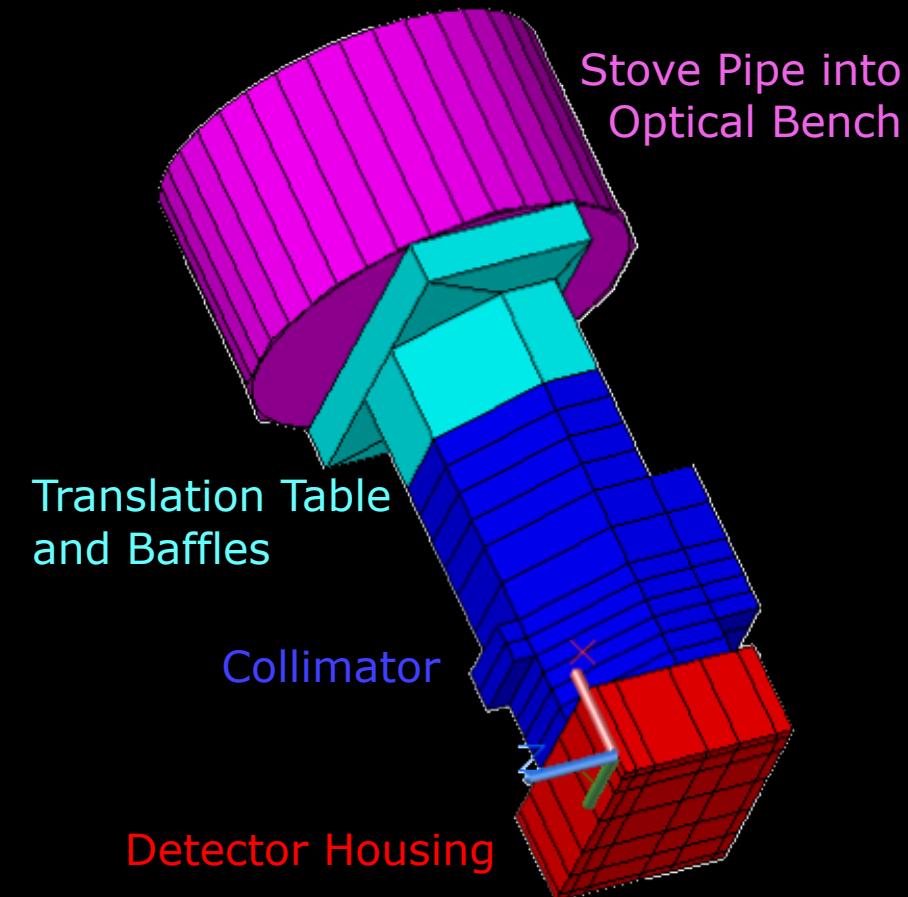
- ACIS operating temperatures
 - Focal plane $T_{FP} = -120^{\circ}\text{C}$
 - Camera housing $T_{DH} = -60^{\circ}\text{C}$
 - $\approx 6^{\circ}\text{C}$ colder with heaters off
 - Optical blocking filters T_{OBF}
 - $\approx T_{DH} \approx -60^{\circ}\text{C}$ near OBF edge
 - 5–20°C warmer near center
- Contamination on cold OBFs
 - Mass column $\approx 200 \mu\text{g cm}^{-2}$
 - $\approx 50 \times$ pre-flight estimates
 - $\leq 1 \text{ g}$ in entire *Chandra* optical cavity (calculated)
 - Thicker near OBF edge
 - Doubled during 2013–2017



Contamination-migration simulations for Chandra



- 2005 (I)
 - Low-resolution geometric model for ACIS cavity
 - 2013 (II)
 - High-resolution geometric model for ACIS cavity
 - Higher emissivity for contaminated surfaces
 - 2015 (III)
 - Same model as 2013
 - 2017 (IV)
 - Extend geometric model into optical bench
- Geometric model (exterior)





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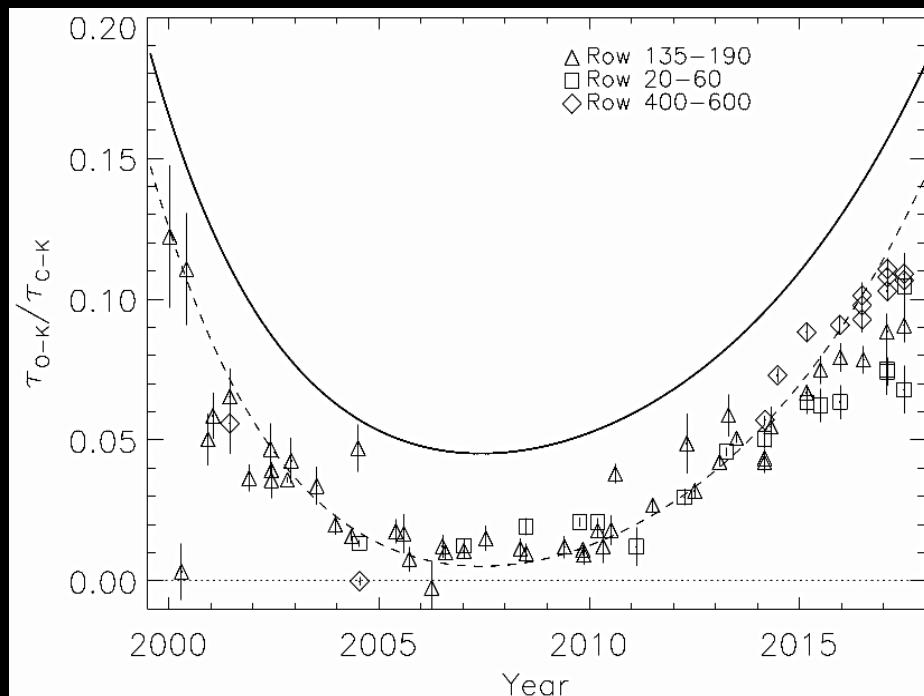
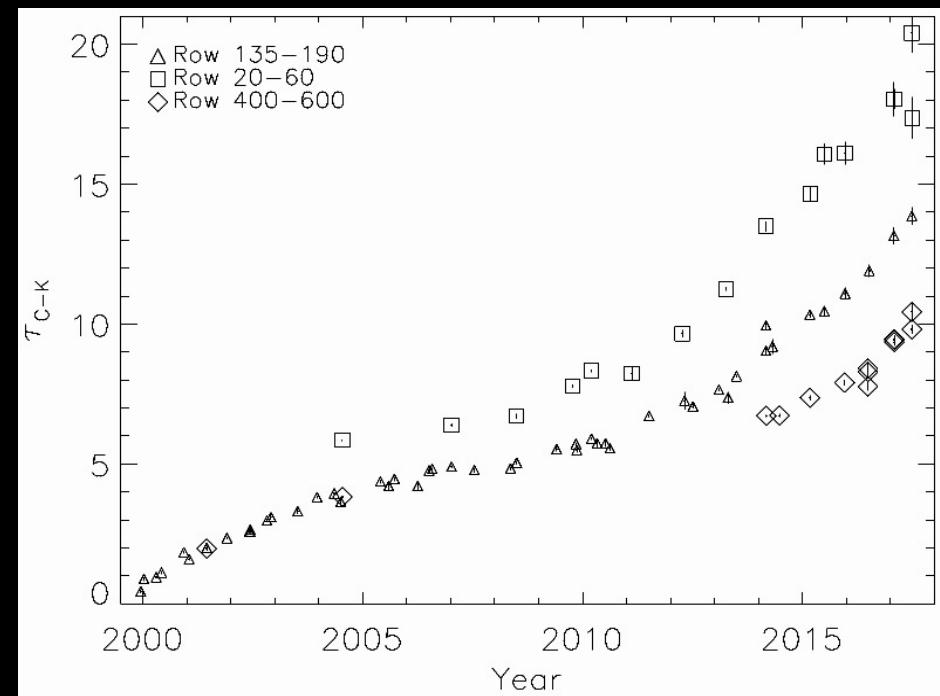
Evolution of mass column, its rate, and composition



- Accumulation of contaminants
 - LETG/ACIS-S spectra
 - Atomic (C,O,F) edge depths
 - Thickest near OBF edges

- Rate fell until about 2008 then started rising
- Multiple species

See next presentation by Herman Marshall

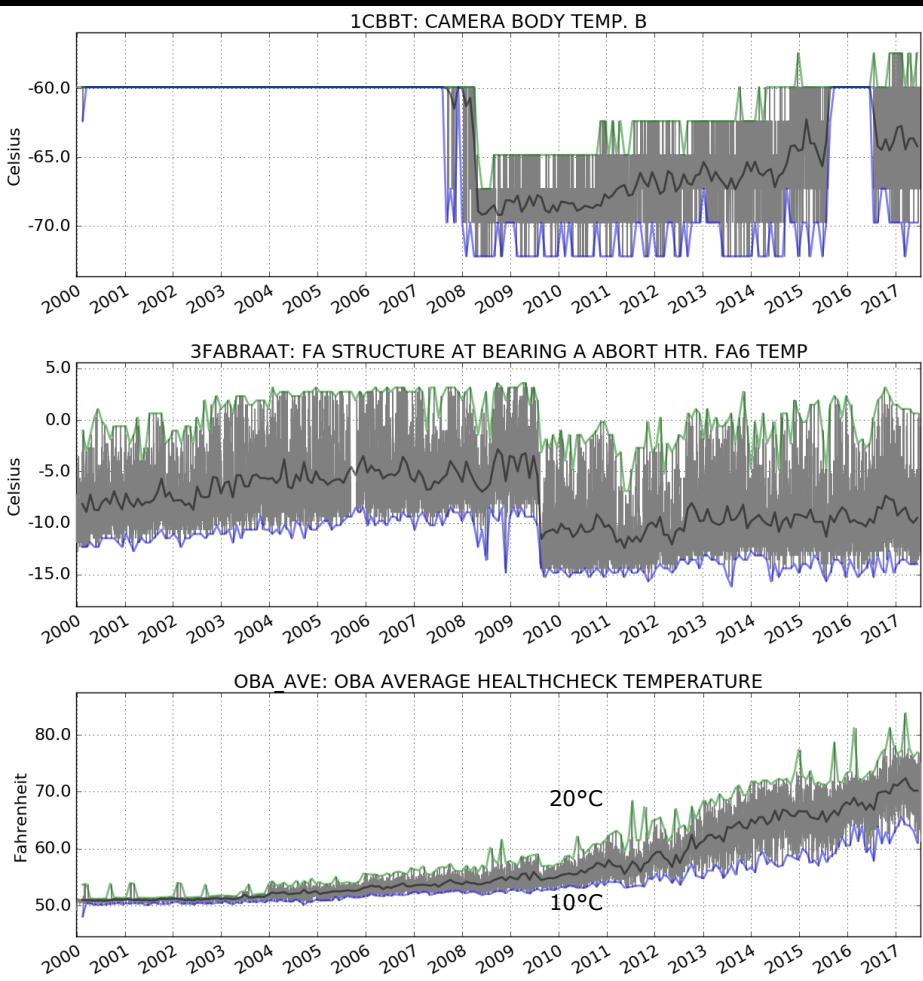




Thermal history



- Most systems are warming
 - Continuing degradation of external insulation (MLI)
- Strive to keep ACIS focal plane cold to preserve performance
 - Carefully plan observations
 - Disabled some heaters
 - ACIS detector-housing heater (2008 April)
 - A SIM focus-assembly heater (2009 August)
- Optical Bench has warmed rapidly since about 2010
 - New contamination source?





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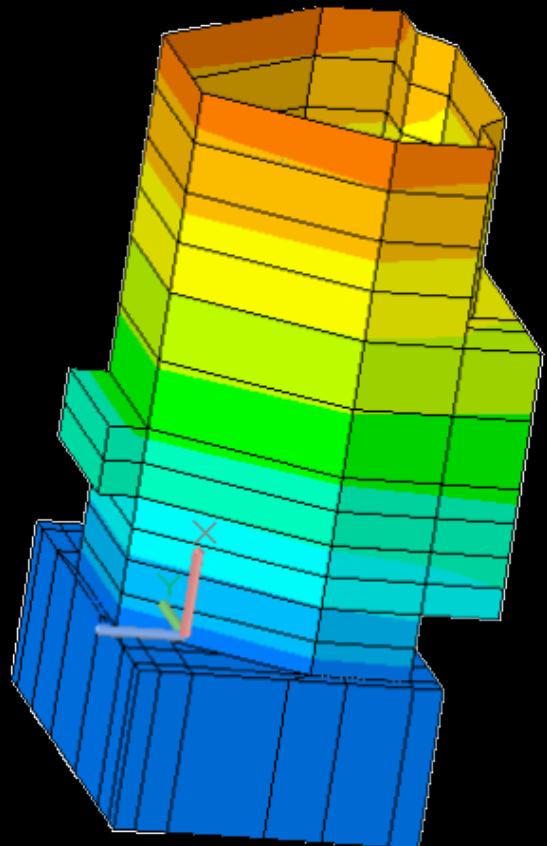


ACIS temperature distribution (exterior)

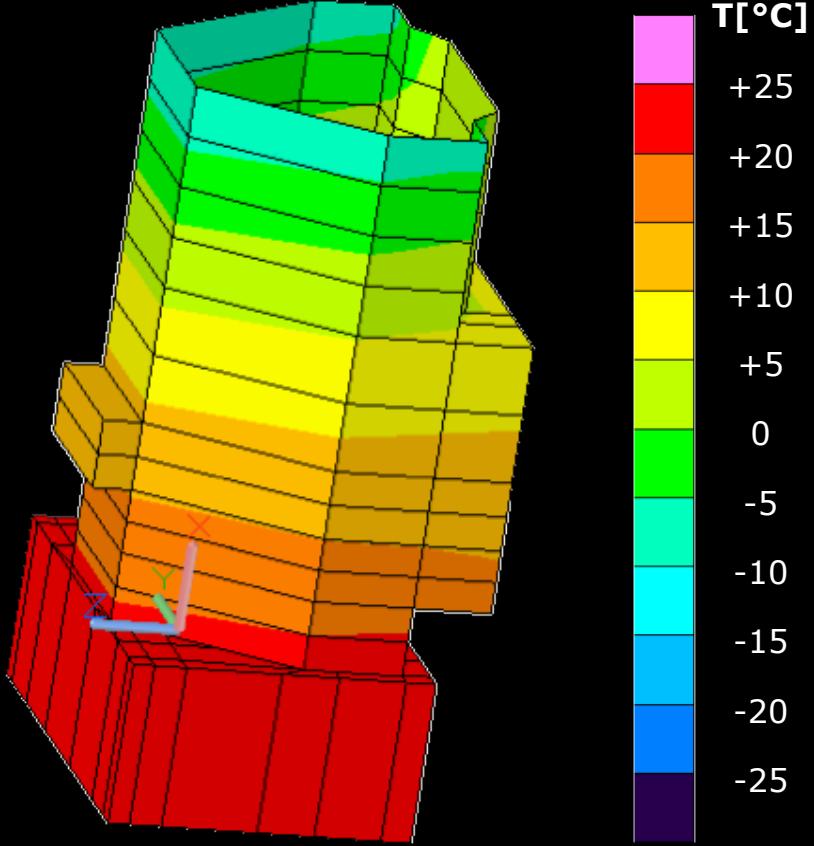
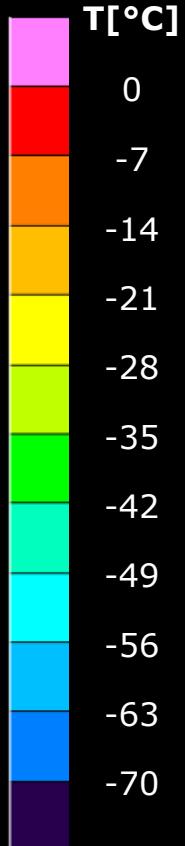


➤ DH heater OFF, $T_{FP} = -120^{\circ}\text{C}$

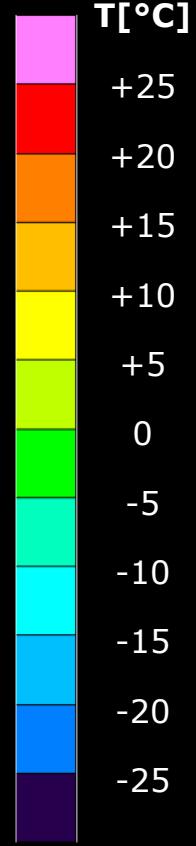
➤ $T_{DH} = +25^{\circ}\text{C}$, $T_{FP} = -60^{\circ}\text{C}$



$$\varepsilon_{OBF} = 0.40$$



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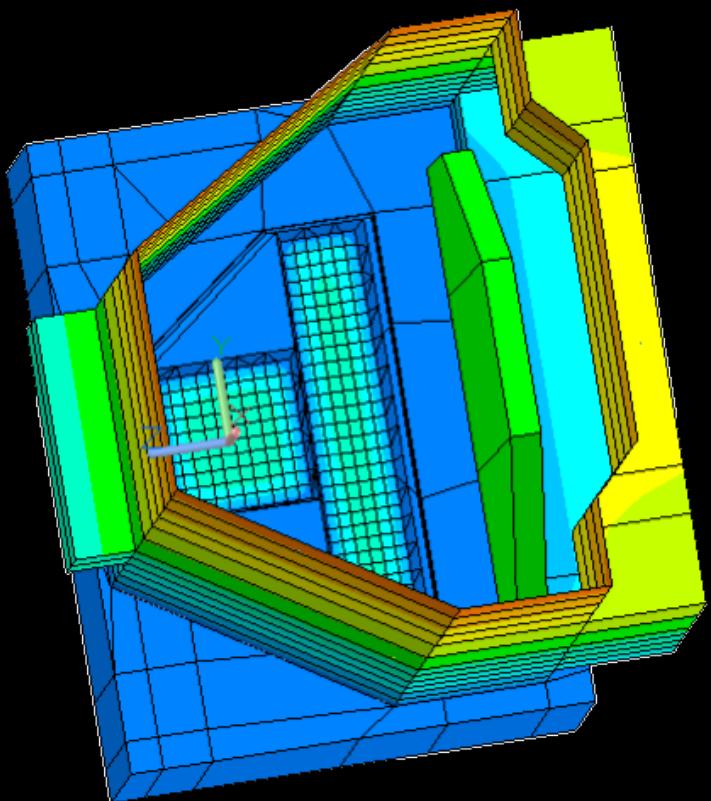




ACIS temperature distribution (interior)

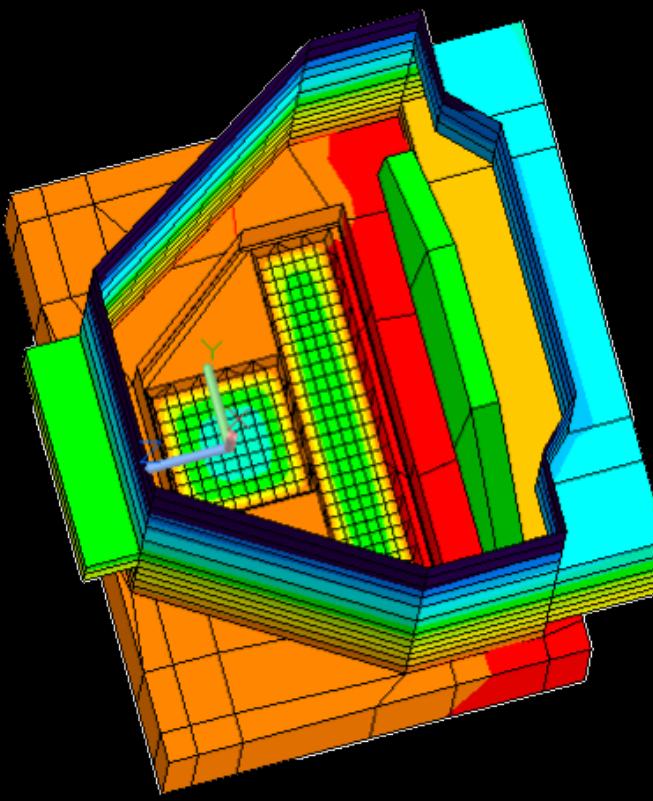


➤ DH heater OFF, $T_{FP} = -120^{\circ}\text{C}$



$$\varepsilon_{\text{OBF}} = 0.40$$

➤ $T_{DH} = +25^{\circ}\text{C}$, $T_{FP} = -60^{\circ}\text{C}$



$$\varepsilon_{\text{OBF}} = 0.40$$



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Molecular flux equations and geometric view factors



➤ Net mass flux onto node j

$$\frac{d\mu_j}{dt} = -\dot{\mu}_v(T_j)\Theta(\mu_j) + \sum_k \dot{\mu}_v(T_k)\Theta(\mu_k) f_{jk} \frac{A_k}{A_j}$$

➤ Mass vaporization flux

□ Related to vapor pressure

$$\dot{\mu}_v(T) = \frac{P_v(T)}{\sqrt{2\pi RT/M}}$$

➤ Clausius–Clapeyron relation

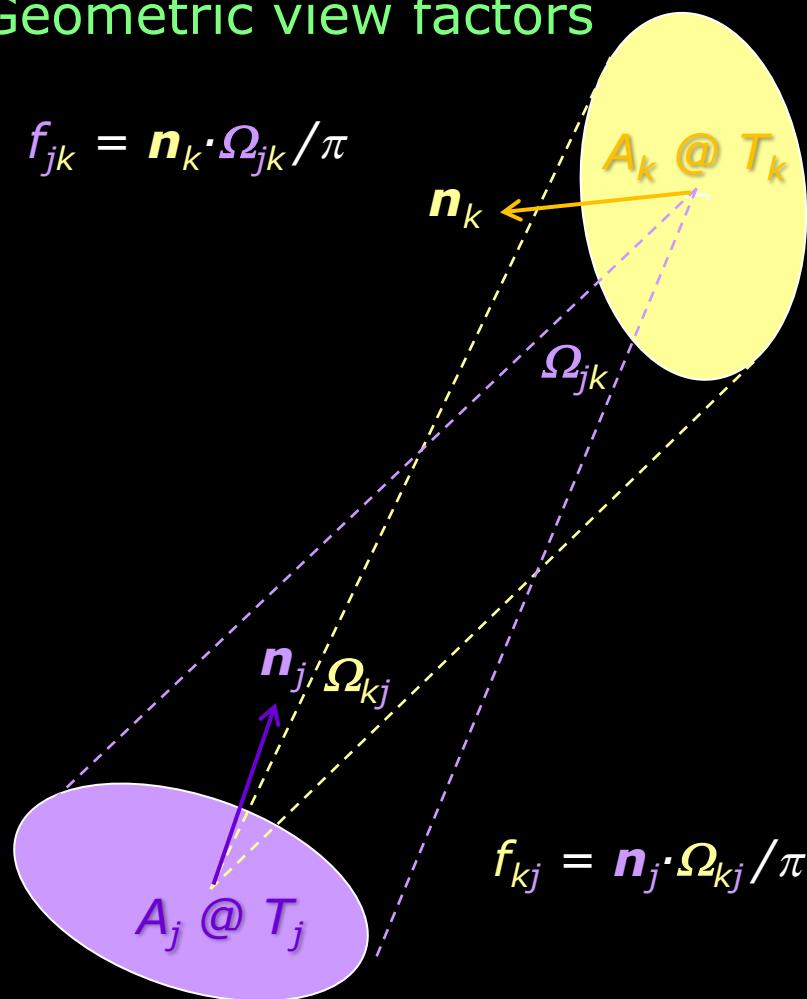
□ Temperature dependence

□ Vaporization enthalpy $\Delta_v H$

$$P_v(T) = P_v(T_\circ) \text{Exp}\left[-\frac{\Delta_v H}{R}\left(\frac{1}{T} - \frac{1}{T_\circ}\right)\right]$$
$$\dot{\mu}_v(T) = \dot{\mu}_v(T_\circ) \sqrt{\frac{T_\circ}{T}} \text{Exp}\left[-\frac{\Delta_v H}{R}\left(\frac{1}{T} - \frac{1}{T_\circ}\right)\right]$$

➤ Geometric view factors

$$f_{jk} = \mathbf{n}_k \cdot \Omega_{jk} / \pi$$

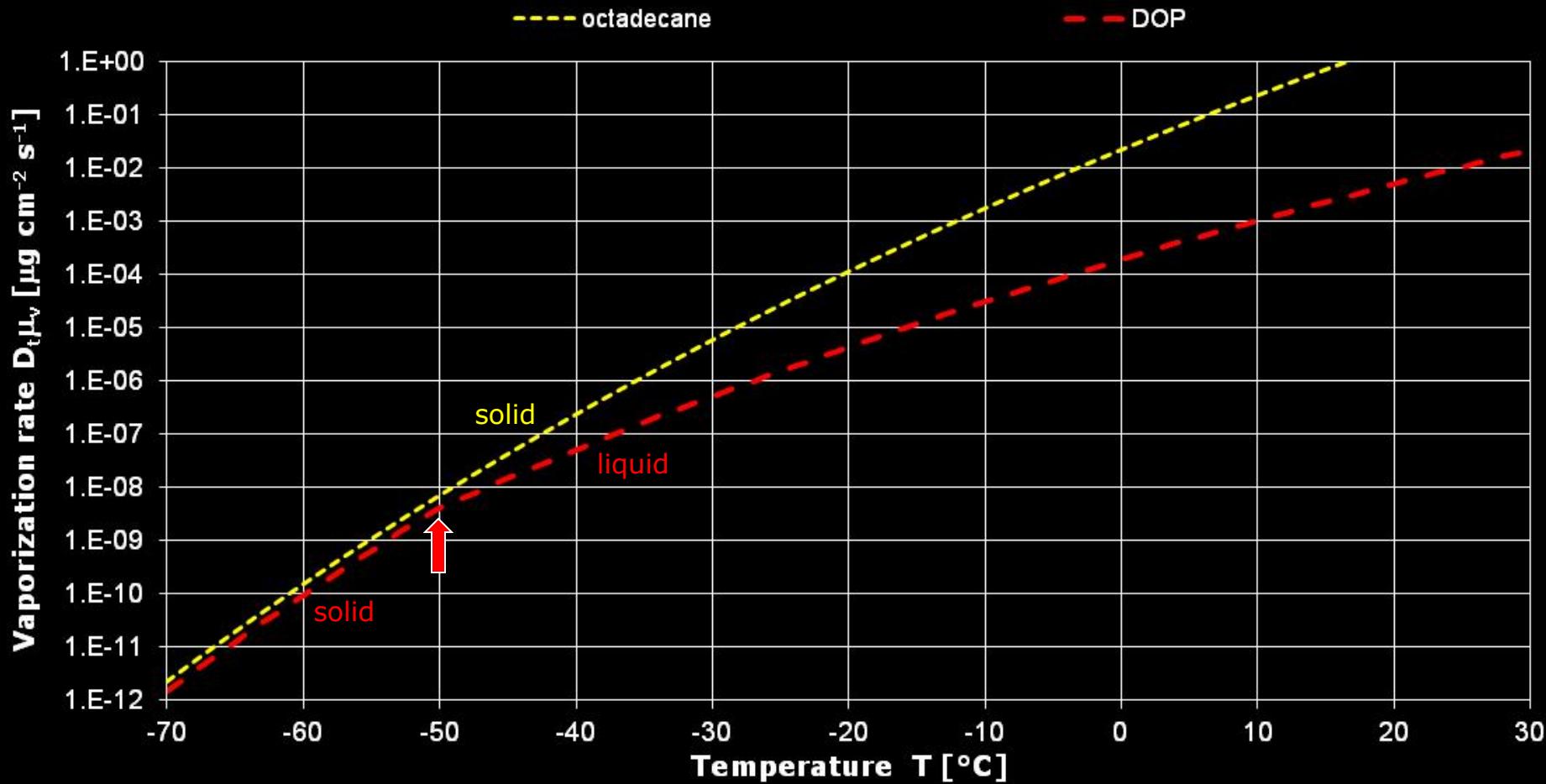




Vaporization rate: Dependence upon phase state



Mass vaporization rates of a solid and of a liquid



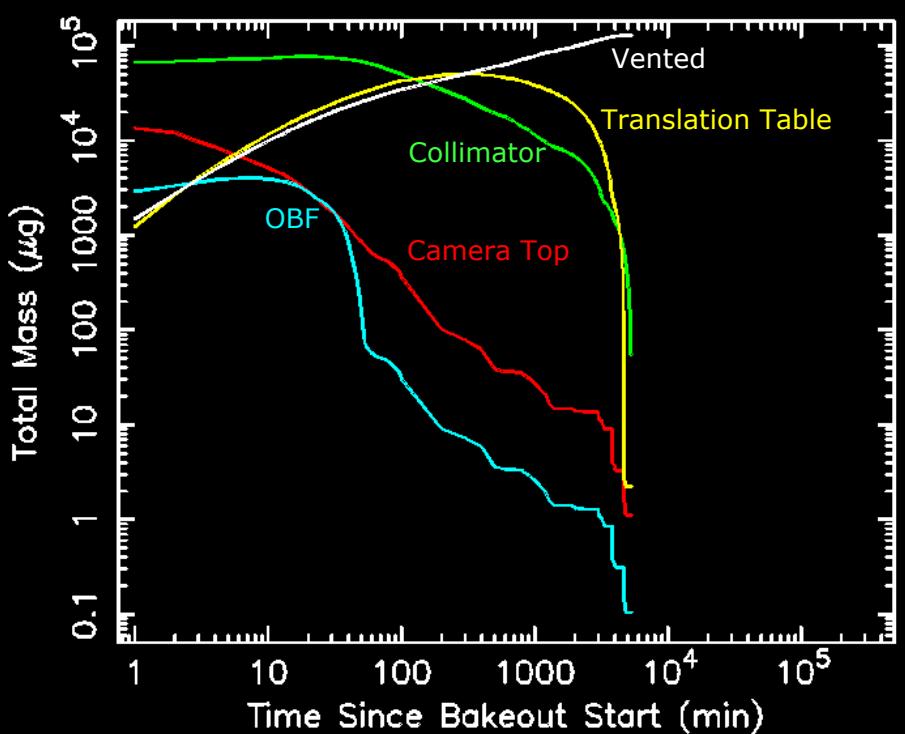


Contaminant mass Cool bake-out

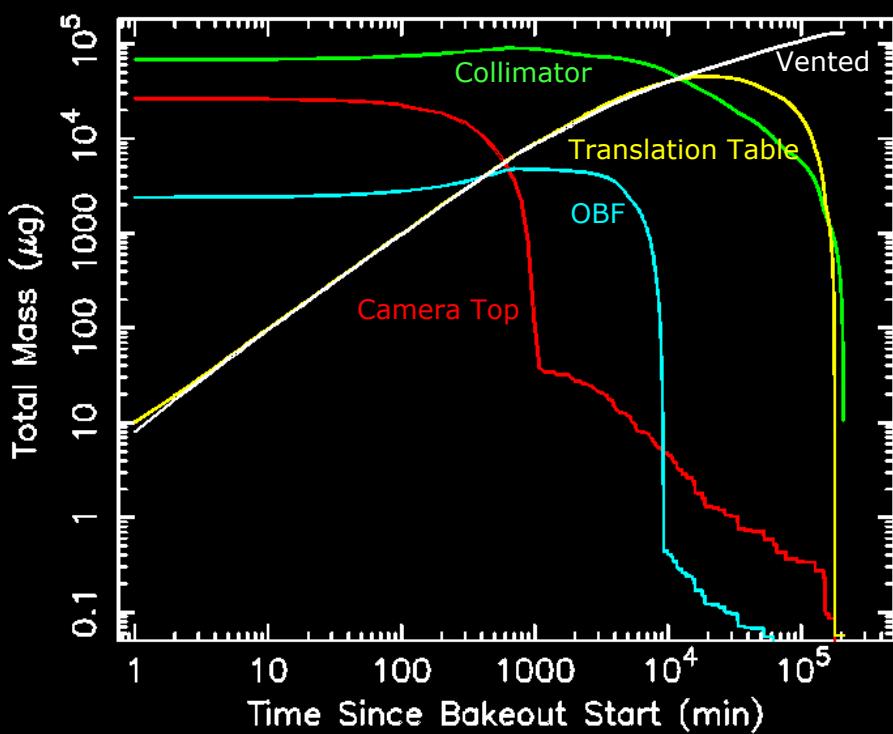


$$T_{FP} = -60^\circ\text{C} \quad T_{DH} = +25^\circ\text{C} \quad T_{OBF} = +10^\circ\text{C} \quad T_{TT} = -10^\circ\text{C}$$

➤ Octadecane



➤ Diethyl phthalate (DOP)



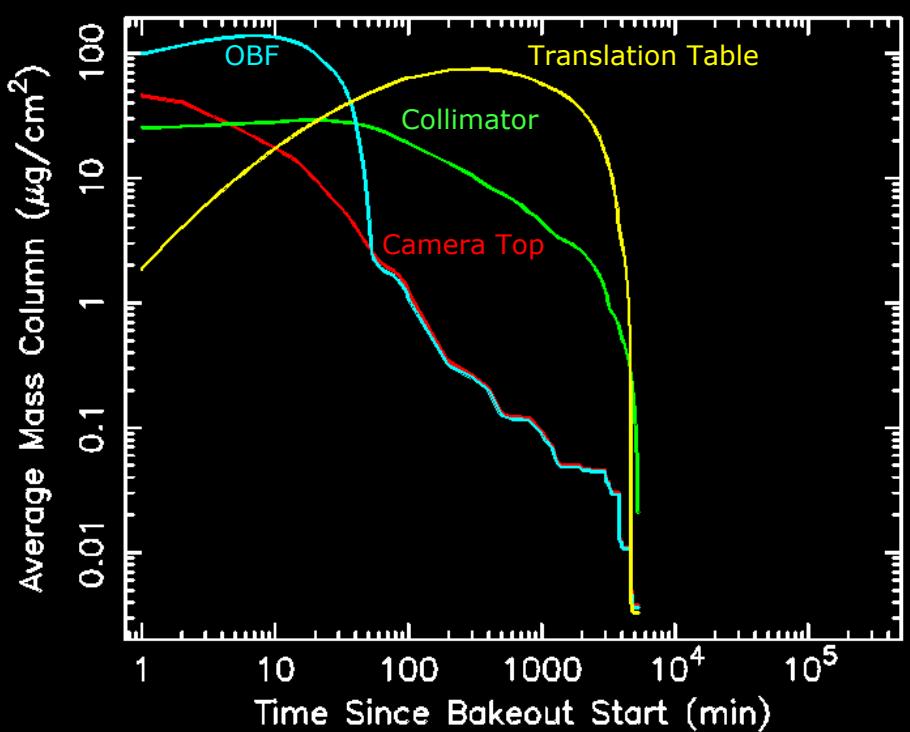


Contaminant mass column Cool bake-out

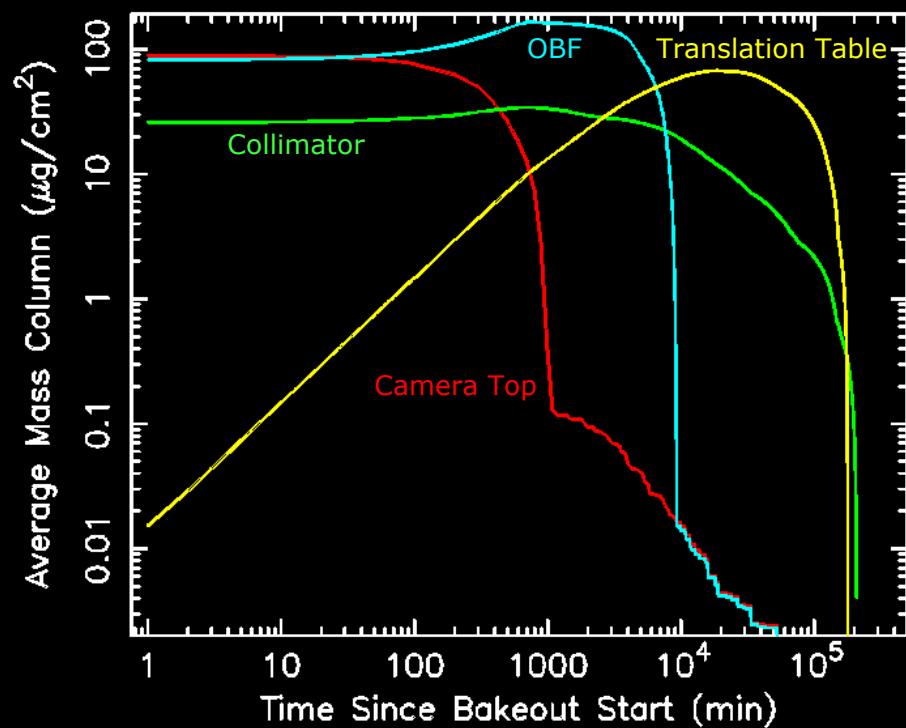


$$T_{FP} = -60^\circ\text{C} \quad T_{DH} = +25^\circ\text{C} \quad T_{OBF} = +10^\circ\text{C} \quad T_{TT} = -10^\circ\text{C}$$

➤ Octadecane



➤ Diethyl phthalate (DOP)



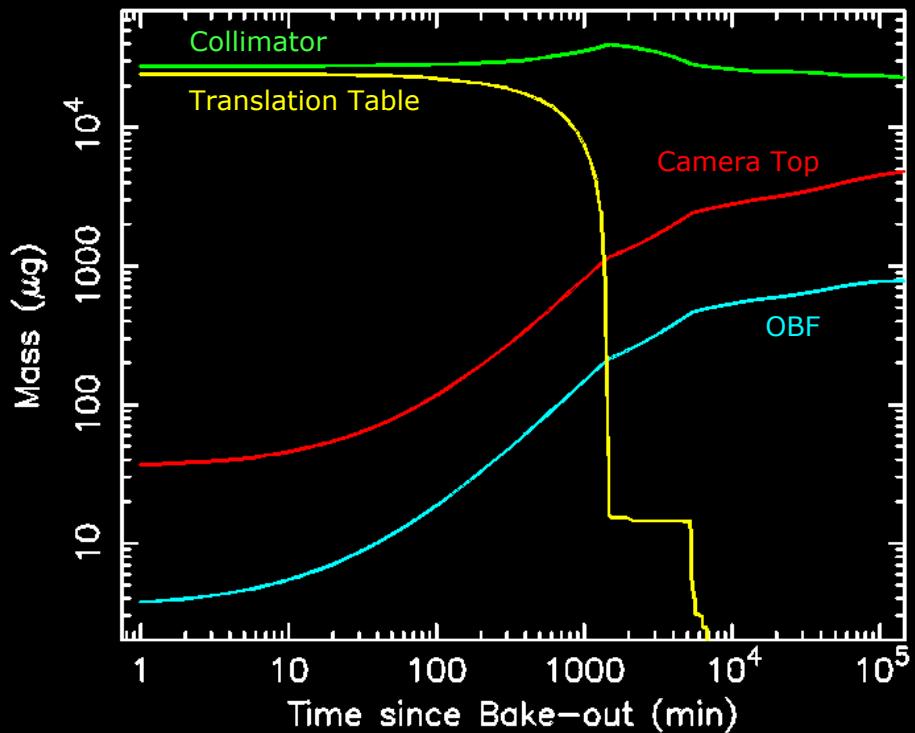


Contaminant re-deposition after (partial) cool bake-out

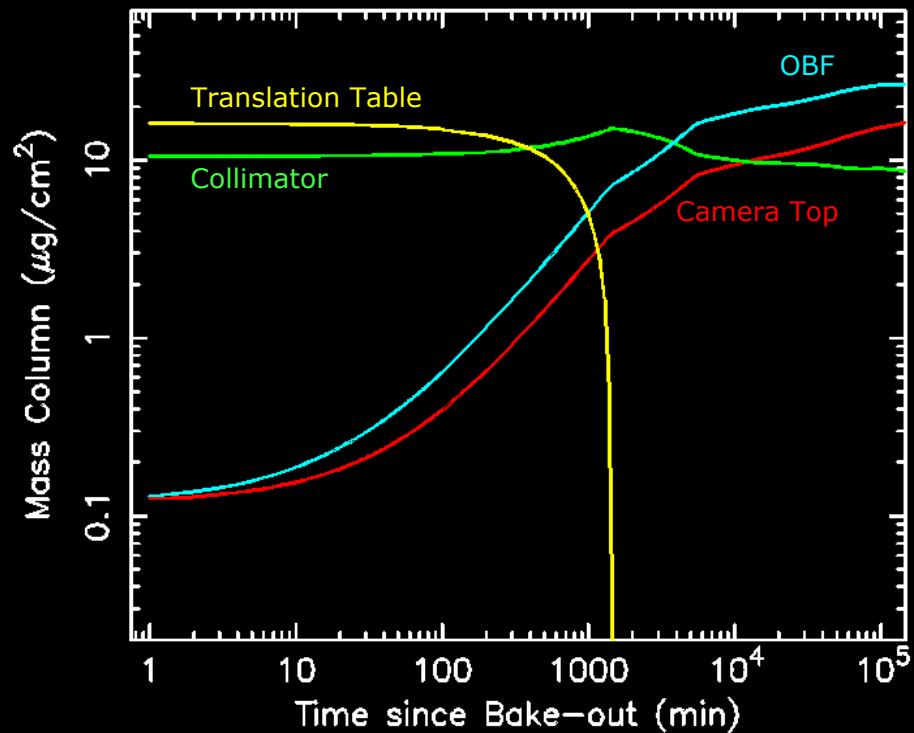


Octadecane/10

➤ Mass



➤ Mass column





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Summary



- Contamination-migration simulation provides a useful tool
 - Utility for absolute predictions is still limited
 - Absolute predictions require knowledge of contaminant's volatility
 - Uncertainty in temperatures propagates exponentially to rate error
 - Model may require additional physics
 - Treatment of multiple molecular species is not simple superposition
 - Dependence of thermal emissivity upon contaminant mass column
 - Surface redistribution, especially for a liquid contaminant
- Chandra Team has again deferred a decision to bake-out
 - Scientific productivity continues despite low-energy absorption
 - Observing proposals remain oversubscribed by factor ≈ 5.5
 - Over 400 refereed papers per year, steady over past decade
 - Identified risks of performing bake-out are small but not zero
 - Bake-out might not substantially reduce contamination on OBFs